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THE LOS ALAMOS SCIENTIFIC LABORATORY ELECTRONIC VEHICLE IDENTIFICATION SYSTEM

by

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Abstract. A three-digit electronic identification system is described. Digits may be decimal (1000 combinations) or hexidecimal (8192 combinations). Battery-powered transponders are interrogated with a low-power (1 W) radio signal. Line-of-sight interrogations up to 33 m (100 ft) are possible. Successful interrogations up to 7 m (20 ft) are possible for concealed transponders (that is, in the engine compartment). Vehicles moving at high rates of speed can be interrogated. This system provides data in a computer-compatible RS232 format. The system can be used for other applications with little or no modification. A similar system is in present use for identification and temperature monitoring of livestock. No unforeseen problems exist for expanding the coding scheme to identify larger numbers of objects.

Introduction

The Los Alamos Scientific Laboratory (LASL) vehicle-identification system is an adaptation of the electronic identification and temperature-monitoring system developed for livestock.[1] Substantial background material can be found in reports of these earlier systems.[2-8]

The system is based on digital coding of the backscatter cross-section of a transponder attached to the object to be identified. The transponder is interrogated by a homodyne radar system, with subsequent digital processing to yield the transponder's number. The transponder is a passive scatterer and generates no microwave energy itself. The digital coding scheme employed eliminates interference and false readings caused by Doppler shifts due to vehicle motion and fan rotation, and sources of electrical noise. Readings are obtained in less than 0.1 seconds.

The system is presently in use at Los Alamos as part of a nuclear safeguards program.

System Functional Description

Familiarity with the fundamental principles of the vehicle-identification system is needed to understand the operation of the system, including basic features and limitations. Technically the system employs modulated backscatter in conjunction with a homodyne radar receiver to relay the coded information.[2] An electronics package is used to process the digital data and convert the data to a useful form.

To help understand the system, Fig. 1 depicts a simple but accurate analogy of the modulated backscatter scheme. The optical transponder or tag contains a unique code wheel and a mirror to change the reflection of light falling on the transponder. An interrogation involves illuminating the transponder with a beam (light from the flashlight) and observing the returned flashing light, much like a simple signal mirror. In the case of Fig. 1, the observer mentally processes the code (perhaps a Morse code) to decipher the transponder's identity or message.

Performance of the vehicle-identification system is accurately depicted in this analogy. For example, if the beam is disrupted (the transponder is hidden behind a building), interrogation is not possible. If the transponder reflects the signal away from the observer and never toward the observer, interrogation is not possible. When the transponder is not illuminated, it cannot be detected since it sends out no signals by itself. Many more traits of this system could be elaborated upon using the analogy of Fig. 1. Instead of doing this, however, we will deal with the electronic realization of this concept so that the reader can develop an appreciation of the actual system.

A typical vehicle-identification system installation is shown in Fig. 2. The transponder is mounted at a convenient and appropriate place on the truck. When the truck reaches the monitoring station, the radio signal from the interrogator antenna illuminates the transponder, which returns a coded

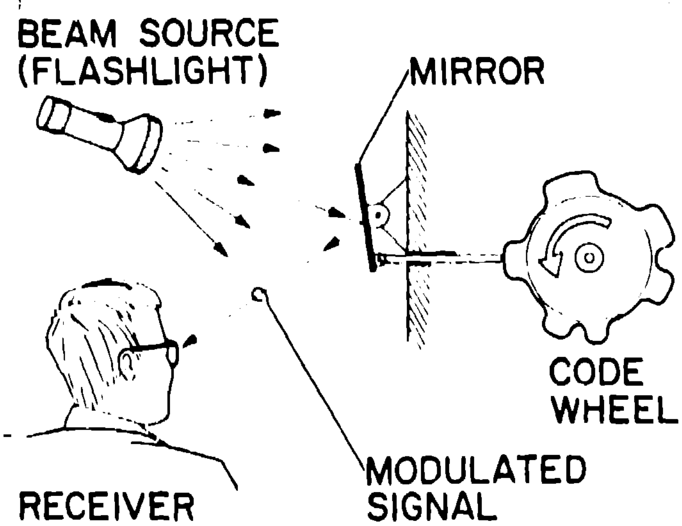

Figure 1. An optical modulated backscatter identification.

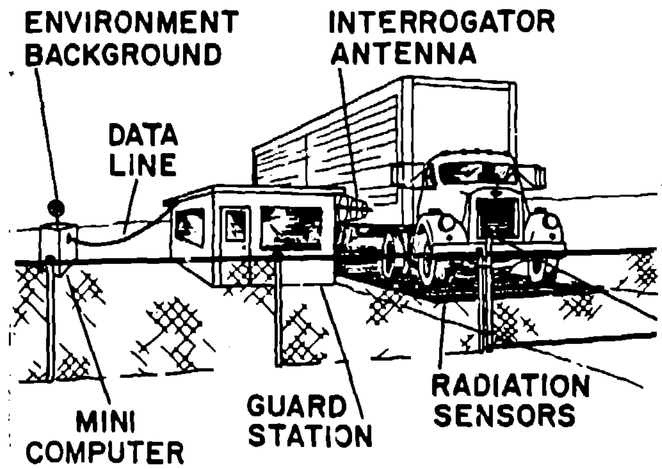

Figure 2. A typical vehicle identification installation.

signal. This return signal is detected in a homodyne radar receiver, much like receivers used by law-enforcement agencies in radar systems for measuring vehicle speed. The detected signal is processed electronically to provide the transponder's identification number. This number can be displayed for visual observation and can be put in a computer-compatible format for automatic processing. The interrogator's antenna system is designed so that a successful interrogation is obtained only from the vehicle in the desired location (and not the one waiting in line behind it). Part of the design of this system includes the location and orientation of the transponder on the vehicle. While this placement is not extremely critical, it is nonetheless very important and must be done with care if the system is to operate properly.

A simplified block diagram of the system is shown in Fig. 3. A control function is not essential, but usually is included in the systems. The control function instructs that the radio transmitter is to be turned on and that a new interrogation is desired. The pulse-modulated signal returned by the transponder is processed to give a detected digital signal in the frequency of 10 to 20 kHz. This signal is amplified and further processed in the interrogator/receiver section to provide the desired outputs. The code is a biphase frequency shift keying (FSK) code using binary coded decimal (BCD). More details on the code can be found in LASL report LA-8612-PR.[1] A power supply is also required but is not shown in Fig. 3.

The receiver employs a two-channel technique. The reference channels are separated by a 90° phase

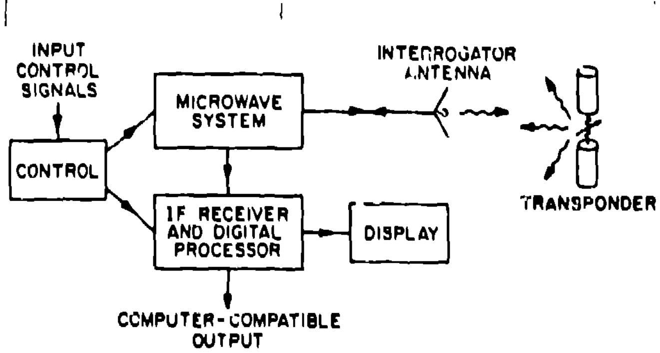

Figure 3. A microwave-modulated backscatter identification.

shift so that the transponder is never in a "null region." A null region would exist in a single-channel homodyne system when the reflected wave and the reference wave were in phase quadrature. The outputs of these two channels are combined in the digital processor.

System Performance

Since the LASL electronic identification system is a nonstandard communications system, a brief discussion of performance is provided here. This summary is intended to show why the interrogation range is much less than the multimile range usually associated with 1 W of transmitted power in a more conventional communications system. Also, features of the system critical to performance are identified.

The IF receiver consists of a limiting amplifier (with a gain in excess of 120 dB) followed by a phase-locked loop. The two-channel input is divided into three channels internally, and a two-out-of-three vote is used to decide the output. Further, the circuitry is arranged to be insensitive to the polarity of the input signal. Signal polarity reversals and nulls are an inherent feature of the homodyne radar system used, thus requiring the receiver characteristics described above. Consequently, receiver sensitivity was measured by inserting a low-level IF signal with a proper code and frequency into the preamplifiers and recording the lowest signal level that would result in a displayed identification number. For a single-channel input, the receiver sensitivity is about 14 μV. For signal on each input channel, the sensitivity is about 7 μV on each channel. This sensitivity is limited by thermal noise and internally generated noise. The front end has a bandwidth from about 500 Hz to 200 kHz. It was also found that power-supply noise in this frequency range can reduce sensitivity.

Conversion of microwave signals to detected IF signals is accomplished through double-balanced mixers. A good discussion of sensitivity and noise of homodyne systems can be found in Microwave Homodyne Systems.[9] King found that the maximum sensitivity of a homodyne mixer using Schottky diodes is about -145 dBm with an output S/N of 3 dB and a bandwidth of 10 Hz. Since the noise is proportional to the bandwidth, maintaining a 3-dB S/N ratio and for a bandwidth of 0.2 MHz, the sensitivity would be -102 dBm or 1.8 μV rms in a 50-Ω system.

Therefore, the receiver sensitivity limits the overall system sensitivity to about -70.3 dBm. This includes directional coupler loss of 0.4 dB, power splitter loss of 0.35 dB per channel (plus the 3-dB power split), and a mixer conversion loss of 10 dB. Often this sensitivity is reduced by spurious modulation on the LO drive (caused by power supplies) or other sources of environmental noise. Most types of noise and spurious responses are rejected by the receiver, however. Long runs of braided coaxial cable can generate impulsive noise as the cable is vibrated. Additionally, standing waves and changes in polarization can cause decreases in expected range.

The radar equation can be used to predict range using the sensitivity numbers given above. The radar equation relates the received power to the transmitted power and other system parameters.

$$P_R = \frac{\sigma A G P_T}{(4\pi)^2 r^4} \text{ watts} \qquad (1)$$

Here, σ = the radar cross section of the target (or change in radar cross section for this system),

A = the effective area of the aperture of the receiving antenna,

G = the gain of the transmitting antenna,

P_T = the transmitted power,

r = the range from the transmitter to the scatterer. (The range from the scatterer to the receiving antenna is assumed to be r also.)

If the same antenna is used for transmitting and receiving, its area can be expressed in terms of its gain, yielding the equation

$$P_r = \frac{\sigma\lambda^2 G^2 P_T}{(4\pi)^3 r^4} \text{ watts.} \tag{2}$$

where λ is the wavelength of the microwave field. For a halfwave dipole,

$$\sigma \approx \lambda^2. \tag{3}$$

Since the FET modulator produces a change of σ, the appropriate number of σ is about $0.2\ \lambda^2$. This gives

$$P_R = \frac{0.2\lambda^4 G^2 P_T}{(4\pi)^3 r^4}. \tag{4}$$

For f = 915 MHz, λ = 0.3279 m, P_T = 1 W, and G = 10 (a typical Yagi antenna),

$$P_R = \frac{1.17 \times 10^{-4}}{r^4}. \tag{5}$$

For P_R = -70.3 dBm or 9.33×10^{-11} W, r = 33.5 m (110 ft.). This is within 10% of the range actually obtained in field trials. This range will be reduced considerably if the transponders are not in line-of-sight but must rely on reflections.

The performance of a conventional communications link is described by the equation

$$P_R = \frac{AGP_T}{4\pi r^2}. \tag{6}$$

A receiver sensitivity of 1 μV is typical for a 10-kHz bandwidth. Thus, for the same parameters as the homodyne system, a range of 1844 km (1145 miles) is to be expected. Usually range of a conventional system is much more limited than this due to conflicting stations operating on the same frequency (the CB skip problem). The vehicle-identification system is not as sensitive to this problem. Many transponders can be fairly close to the interrogation site without interfering with the successful interrogation of the desired unit. Interrogation

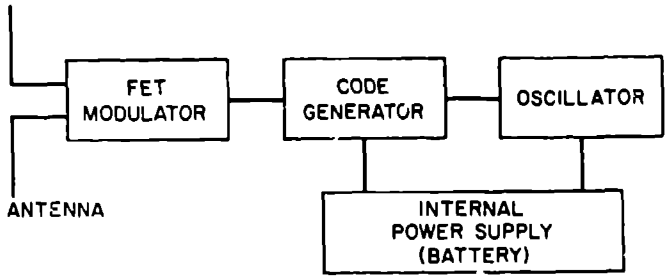

Figure 4. Transponder block diagram.

units may interfere with each other if they are using the same radio frequency and are within several hundred feet of each other, however.

Electronics Details

Transponders

Figure 4 shows a block diagram of the transponders. Presently, the transponders are constructed on G-10 printed-circuit boards using DIP packages, as shown in Figs. 5a and 5b. The battery is a 3-V lithium C cell with a capacity of 3 A-H and a shelf life in excess of 10 years. The CMOS circuitry draws about 30 μA; thus, the battery will theoretically last at least 11 years. The transponder is powered continuously. Coding is done just prior to encapsulation for vehicle mounting. A vehicle-ready transponder is shown in Fig. 5c.

A high-frequency FET transistor is used as the microwave modulator and is placed at the center of a dipole antenna. The oscillator operates at 40 kHz, although this frequency could be made proportional to some analog signal and used as a telemetry system. (In livestock applications, the oscillator rate is controlled by body temperature.) The digital code is provided by switching from 10 kHz to 20 kHz in a coded fashion. The code is stored as a series of opens or shorts at the output of an analog switch.

Interrogator

The interrogator consists of a dual-channel homodyne radar followed by a digital processor. The choice of microwave frequency depends most heavily

Figure 5a. Solder side of printed circuit board.

Figure 5b. Component side of printed circuit board.

on frequency authorizations. Presently, a 1-W, 915-MHz source is used. Local oscillator (LO) power for the mixers is obtained by a directional coupler. The returned modulated signal is fed to the mixers via a circulator. Power splitters are used on both the LO lines and on the return signal line. A 90° phase shift is inserted in one of the lines to get around the quadrature null problem. The mixers are followed by a moderate level of amplification, and then by a three-channel limiting amplifier. Two of the limiting amplifier channels are obtained from the amplified mixer outputs, the third from the sum of the amplified mixer outputs. In this way, a two-out-of-three vote always gives good data as only one of these channels is ever null.

The remainder of the digital processor consists of a phase-locked loop, FSK demodulator, biphase demodulator, and error detectors. For an identification number to be considered valid, it must be obtained identically three times in succession. Display circuitry and data output ports are also provided.

This unit was designed for 120 Vac operation. The design is adaptable to miniturization, and a small hand-held interrogator has been constructed as well.

Figure 5c. A vehicle-ready transponder.

Summary

An electronic identification system has been described that is presently in use for the automatic identification of vehicles in a nuclear safeguards program. The system is also adaptable to other automatic identification applications. The transponders placed on the items to be tagged are potentially inexpensive. The system is reliable, providing essentially no erroneous readings and very few missed readings. Vehicles traveling at high rates of speed can be identified. The present system is limited to 8192 unique identification numbers. This capability could be expanded easily.

Acknowledgments

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